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Validation of 3TIER Simulations

Tower BPA107 (Wasco, OR)

for Bonneville Power Administration

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1 Executive summary

3TIER has been retained by Bonneville Power Administration (BPA) to assess the wind resource across the Northwest United States utilizing a numerical weather prediction (NWP) model. This validation report examines the quality of the NWP simulations used for that assessment at a single point within the study area.

The results presented in this validation report are preliminary results because the model simulations are not fully complete.

The average observed wind speed (for all valid observational times) at 30 meters during the 12 months of the period of record (January, 2006 to December, 2006) was approximately 6.03 m/s with an hourly standard deviation of 3.25 m/s. This compares to a mean simulated 30m wind speed of 5.59 m/s and standard deviation of 2.91 m/s for these same times.

Section 2 of this report describes the on-site meteorological data sources used in this analysis. The NWP model used in this study is described in Section 3. Section 4 describes how well the on-site observational data compare to the simulated time series along the following metrics:

a. Monthly-mean wind speeds (Section 4.1)
b. Hourly distribution of wind speeds (Section 4.2)
c. Hourly distribution of wind direction (Section 4.3)
d. Diurnal characteristics of the wind resource (Section 4.4)

2 Observational Data

Approximately 12 months of data (January, 2006 to December, 2006) from a 30m meteorological tower (Tower BPA107) near Wasco, OR were used in this analysis. This tower will be referred to as the reference tower throughout this report. The data at 30 meters were used to assess the quality of the NWP model simulations at 30 meters.

It should be noted that meteorological observations provided to 3TIER are not allowed to influence the NWP model simulations.

3 Model simulations by 3TIER

3TIER has configured a mesoscale NWP model to simulate the wind resource over the Northwest United States. Table 2 in Appendix A lists some of the details of the NWP model configuration. The NWP model utilizes a nested grid layout. The extent of the coarsest model grid is selected to capture the effect of synoptic weather events on the wind resource in the region of interest, as well as to allow the model to develop regional thermally-driven circulations. The increasingly fine 54km, 18km, 6km, and 2km grids are used to accurately simulate the effect of local terrain and local scale atmospheric circulations. Data from the innermost high resolution grid are used for this validation study. Figure 1 shows the boundary of the two finest resolution grids covering the simulated region. The border of the valid study area, simulated at 2km resolution, is denoted by the innermost black box in Figure 1.

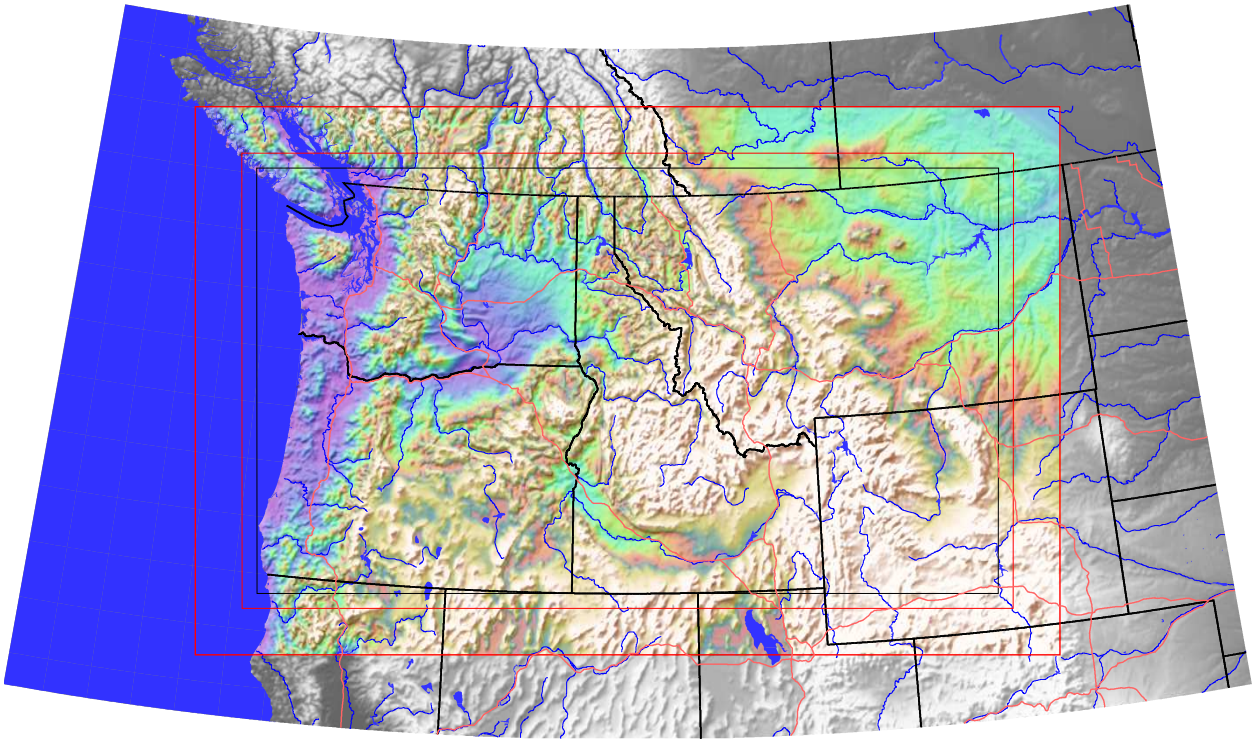

Figure 1: The red boxes denote the boundary of the 6km and 2km resolution nested grids. The innermost black box denotes the boundary of the valid study area simulated at 2km resolution.

4 Model validation

This section presents a comparison of the NWP model simulated winds with the observations at the reference tower. The focus of the verification is on the model's ability to reproduce the observed variability of the wind resource at daily and monthly time scales, while preserving the distribution of hourly wind speeds and the diurnal characteristics of the wind.

Table 1 shown below presents some basic statistical measures of the model performance relative to the measured winds at the reference tower during the observational period. The model succeeds in capturing most of the variance at the site on monthly and daily time scales.

Table 1: Comparison of NWP model data to on-site observations

Comparison	Value
Correlation of monthly-mean simulated winds to observed	0.53
RMS error of monthly-mean simulated winds	0.79 m/s
Correlation of daily-mean simulated winds to observed	0.62
RMS error of daily-mean simulated winds	1.97 m/s

4.1 Monthly-mean wind speeds

Figure 2 compares the simulated and observed monthly-mean wind speeds for each month during the period of record. Figure 2 also lists the r-squared value of each data source relative to the reference tower. For reference, the correlation of the reference tower winds to itself is perfect and hence the r-squared value is 1.0.

The observed and modeled wind speeds shown in Figure 2 represent the mean of all times during the month for which both a valid wind speed observation and valid model data were available at the reference tower. Therefore they should not be interpreted as estimates of the true monthly-mean wind speeds at the site, but rather a verification of the model's ability to reproduce the available observed wind speeds. Any month missing greater than 50.0% of the available observations or model data is omitted from Figure 2. These month(s) are also not included in the monthly-mean statistics shown in Table 1 or the explained variance (r-squared) values displayed in Figure 2.

The average observed wind speed at the reference tower for all times with valid observational and model data during the period of record is 6.03 m/s. This compares to a modeled 30m wind speed of 5.59 m/s for these same times. Table 3 in Appendix B presents monthly-mean statistics comparing observational wind speed data to the simulated model output.

4.2 Distribution of wind speeds

Figure 3 displays the hourly wind speed distributions for the observed and simulated data. Also shown in Figure 3 are the fitted Weibull distributions. The Weibull scale parameter, A, and shape parameter, k, are given in the legend. Tables 8 and 9 in Appendix D contain the observed and simulated values plotted in Figures 3. Distribution values binned by wind direction are also included in Tables 8 and 9.

4.3 Distribution of wind direction

Figure 4 compares the prevailing observed and simulated wind directions. Tables 6 and 7 in Appendix D show the observed and simulated frequencies plotted in Figure 4. Tables 6 and 7 also contain mean wind speed values and Weibull parameters for each wind direction sector.

4.4 Diurnal characteristics of the wind resource

Figure 5 compares the diurnal characteristics of the observed and simulated winds over the period of record of the reference anemometer. Figure 6 presents the simulated diurnal cycle for each individual calendar month. Tables 4 and 5 in Appendix C show the diurnal cycle of observed and simulated wind speeds for each calendar month.

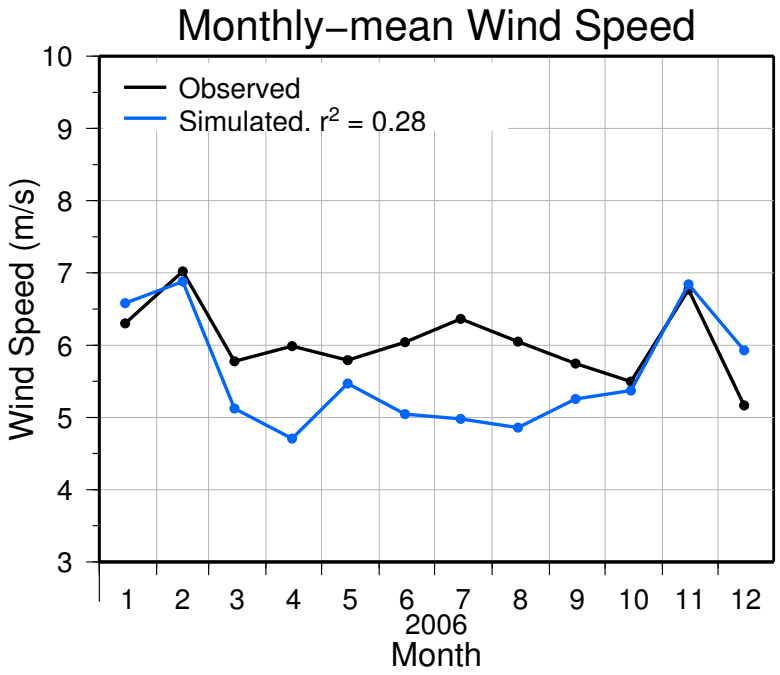

Figure 2: Time series of monthly-mean 30m wind speed at the reference tower. Months missing greater than 50.0% of the available observations or model data are not plotted. (Tabular formatted data available in Tables 3 of Appendix B.)

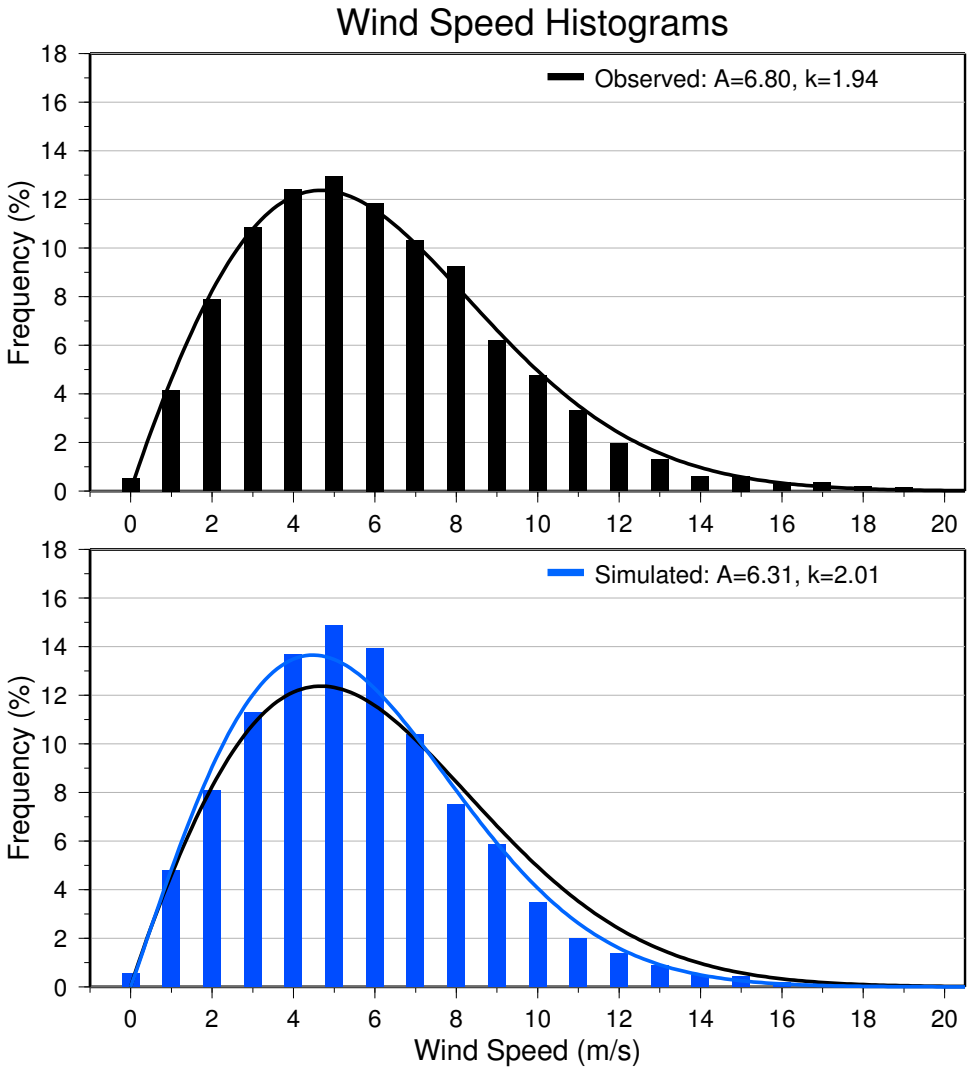

Figure 3: Hourly distributions of $30m$ wind speed at the reference tower using $1\,m/s$ bins. ($0\,m/s$ bin contains only values $\leq$ 0.5) Fitted Weibull distributions are also displayed with the scale(A) and shape(k) parameters listed in the legend. (Tabular formatted data available in Tables 8 and 9 of Appendix D.)

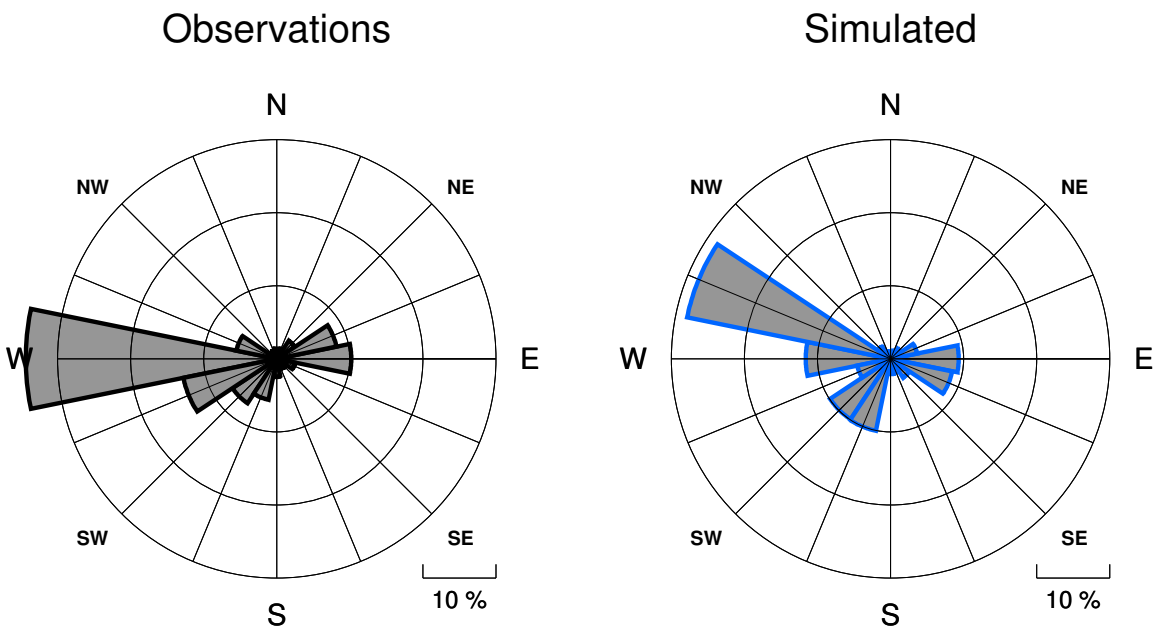

Figure 4: Wind roses at the reference tower for observational data and simulated model output. Directional bins are 22.5° wide, and the radial contour interval is 0.1, i.e. 10%. (Tabular formatted data available in Tables 6 and 7 of Appendix D.)

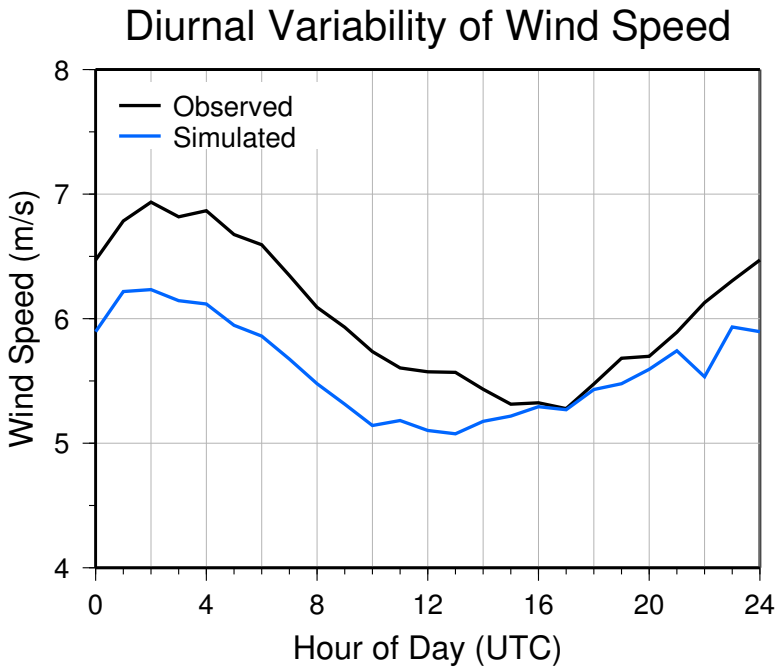

Figure 5: Diurnal cycle of 30m wind speed at the reference tower. Hours missing greater than 50.0% of the available observations or model data are not plotted. (Tabular formatted data available in Tables 4 and 5 of Appendix C.)

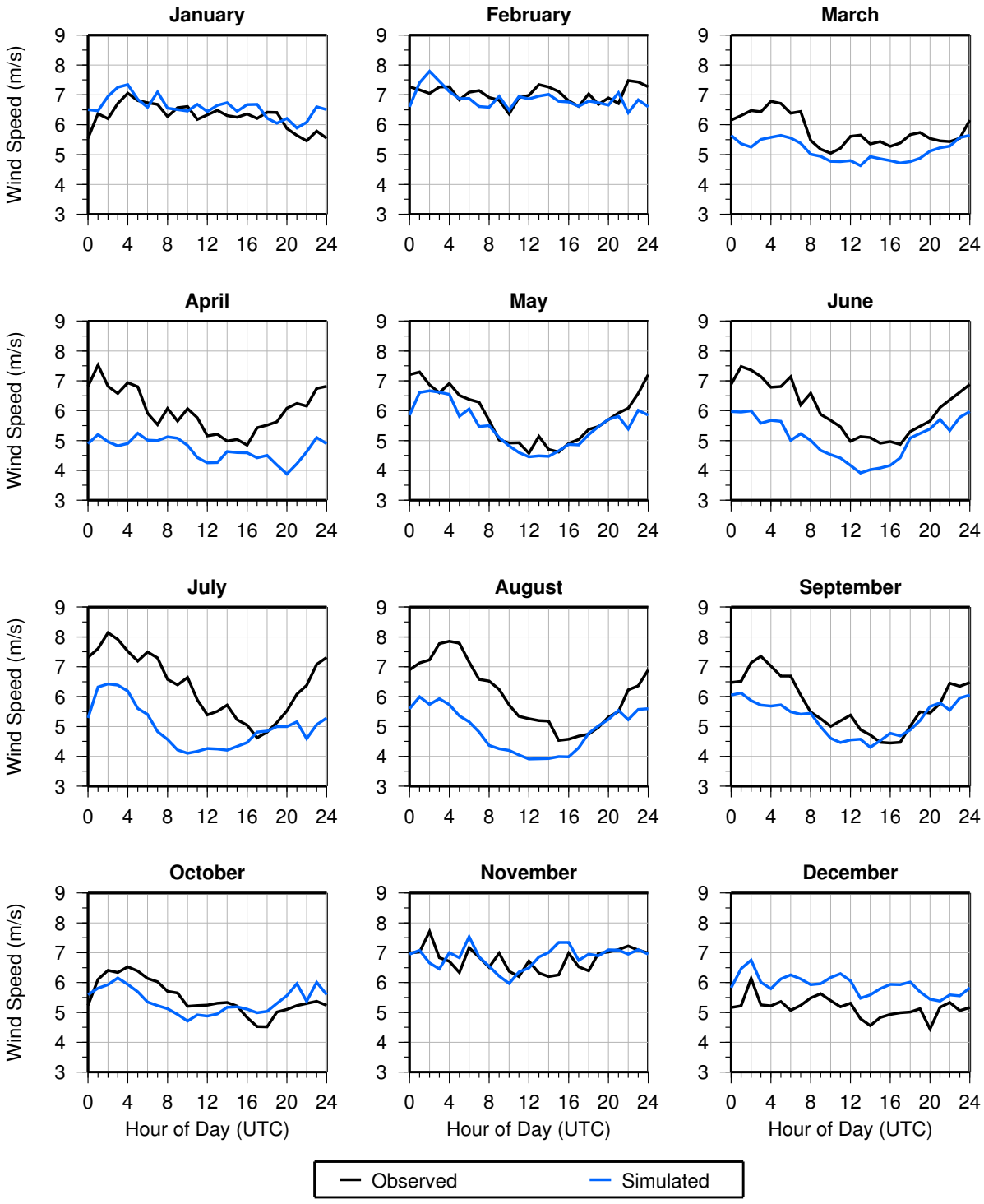

Figure 6: Diurnal cycle of 30m wind speed for each month. Hours missing greater than 50.0% of the available observations or model data are not plotted. (Tabular formatted data available in Tables 4 and 5 of Appendix C.)

Appendix A NWP Model Details

Table 2: Numerical weather prediction model configuration

Parameter	Value
Mesoscale numerical weather prediction model	WRF
Number of vertical levels	31
Elevation data base	3 second USGS
Vegetation data base	30 second USGS
Soil classification	30 second USGS
Surface parameterization	Monin-Obukhov similarity model
Boundary layer parameterization	YSU model (MRF with entrainment)
Land surface scheme	5-layer soil diffusivity model

Appendix B Monthly-mean Tables

Table 3: Monthly-mean wind speeds (m/s)

Month	Observed	Simulated	Bias	Data availability(%)
01/2006	6.30	6.58	0.28	96.8
02/2006	7.02	6.88	-0.14	89.0
03/2006	5.78	5.12	-0.65	99.2
04/2006	5.99	4.71	-1.28	90.8
05/2006	5.79	5.47	-0.32	94.4
06/2006	6.04	5.05	-1.00	96.5
07/2006	6.36	4.98	-1.38	80.4
08/2006	6.05	4.86	-1.19	95.2
09/2006	5.75	5.26	-0.49	88.7
10/2006	5.50	5.37	-0.12	97.2
11/2006	6.77	6.84	0.07	98.9
12/2006	5.17	5.93	0.76	96.1
All	6.03	5.59	-0.44	93.6

Observed = mean of observational data for times with simulated data
Simulated = mean of simulated model output for times with observations
Bias = Simulated - Observed

Appendix C Hourly-mean Tables

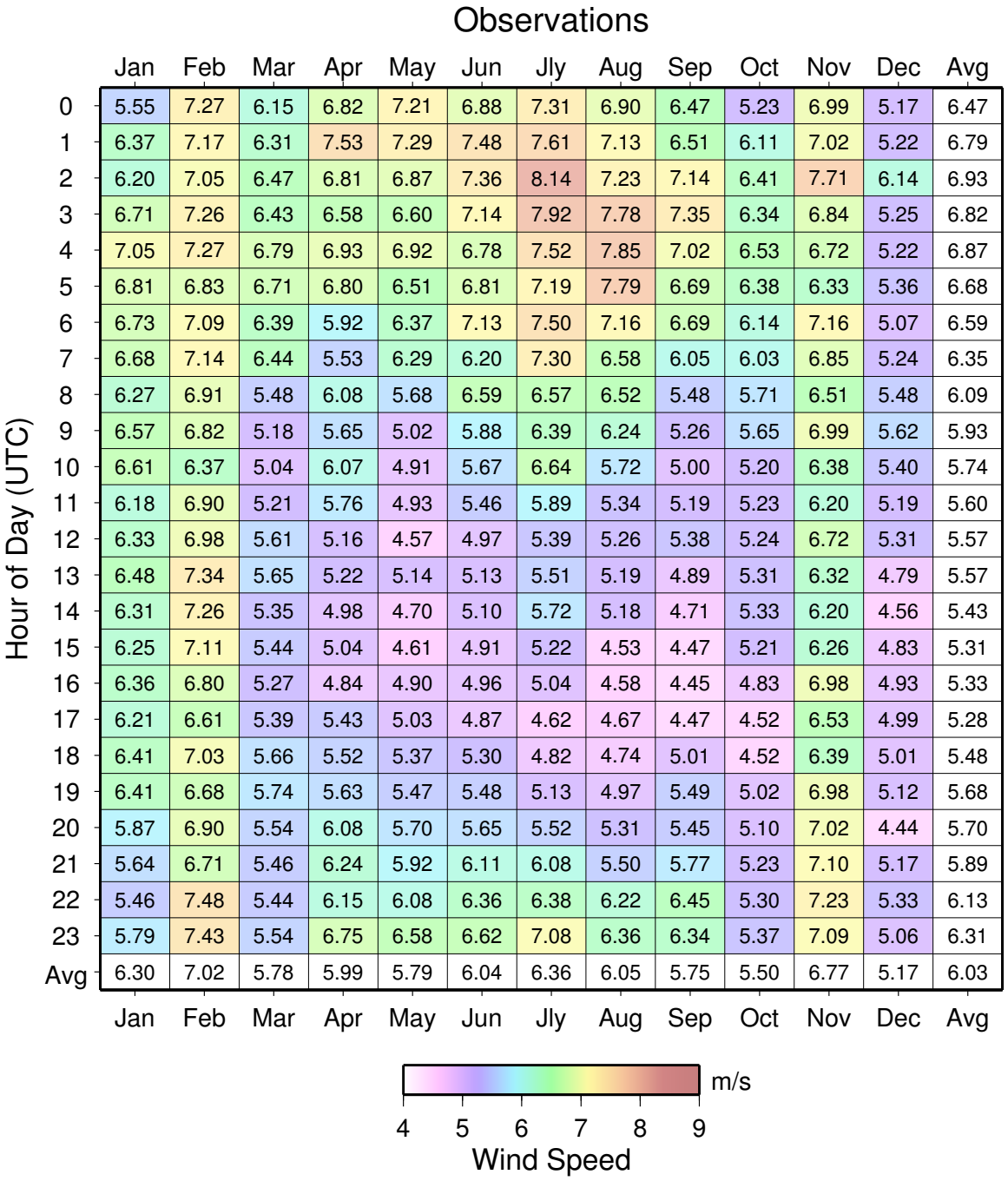

Table 4: Hourly-mean observed wind speed values by month. Times missing greater than 50.0% of the available observations or model data are not plotted.

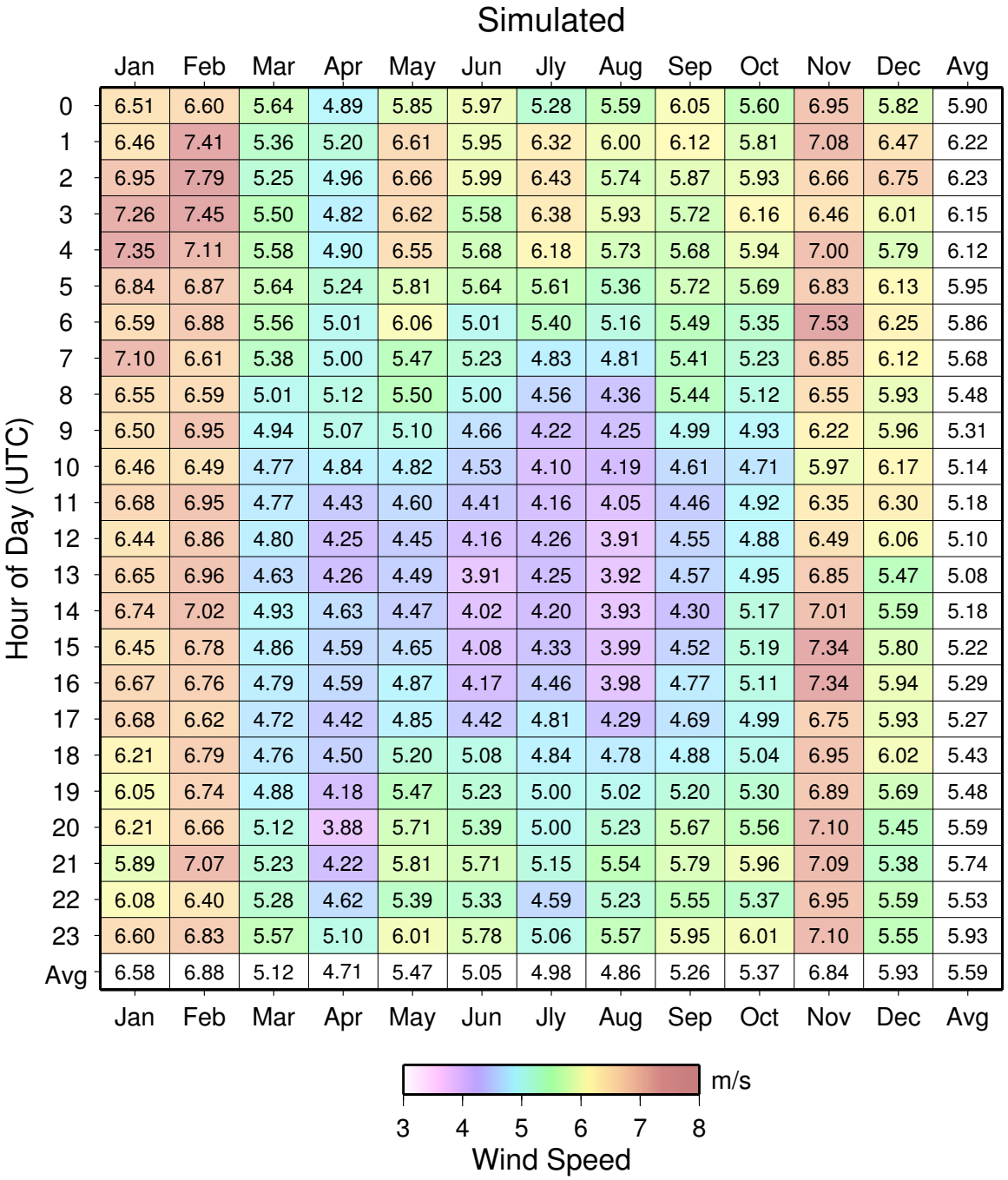

Table 5: Hourly-mean simulated wind speed values by month. Values are computed only for times with valid observations. Times missing greater than 50.0% of the available observations or model data are not plotted.

Appendix D Histogram Tables

Table 6: Observed mean wind speed, Weibull parameters, and frequency

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	2.22	2.50	2.19	1.40
NNE	2.45	2.76	1.74	1.24
NE	6.12	6.75	1.45	2.95
ENE	6.72	7.58	2.34	8.33
E	5.41	6.08	2.70	10.19
ESE	3.54	3.98	1.85	2.55
SE	3.84	4.27	1.54	1.48
SSE	4.71	5.25	1.60	1.26
S	5.49	6.12	1.60	2.46
SSW	7.87	8.85	1.85	5.71
SW	6.66	7.38	1.51	7.27
WSW	5.50	6.20	1.89	13.05
W	6.68	7.49	2.88	34.35
WNW	5.97	6.73	1.96	5.63
NW	2.68	3.01	1.83	0.96
NNW	2.11	2.37	1.81	1.17
ALL	6.03	6.80	1.94	100.0

All observational values are computed only for times with valid model data
Blank values correspond to times with less than 10 data points.

Table 7: Simulated mean wind speed, Weibull parameters, and frequency

Sector	Mean Speed(m/s)	Weibull Scale(A)	Weibull Shape(k)	Frequency(%)
N	2.60	2.93	2.27	0.71
NNE	2.97	3.35	1.99	1.15
NE	4.24	4.69	1.48	1.67
ENE	5.86	6.60	1.85	3.69
E	6.17	6.94	2.60	9.33
ESE	5.59	6.25	3.12	8.61
SE	3.93	4.43	1.98	3.11
SSE	4.01	4.44	1.49	1.94
S	4.74	5.30	1.64	2.09
SSW	6.55	7.39	2.32	10.04
SW	5.97	6.73	1.93	9.93
WSW	4.76	5.29	1.53	4.65
W	5.41	6.09	1.83	11.61
WNW	5.98	6.75	2.35	28.41
NW	3.31	3.73	1.89	2.04
NNW	2.54	2.86	1.85	1.05
ALL	5.59	6.31	2.01	100.0

All model values are computed only for times with valid observations
Blank values correspond to times with less than 10 data points.

Table 8: Distribution of observed wind speed by direction

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.04	0.04	0.07	0.01	0.04	0.04	0.06	0.01	0.02	0.02	0.01	0.04	0.04	0.05	0.00	0.05	0.54
0.5 - 1.5	0.27	0.26	0.22	0.23	0.30	0.34	0.23	0.15	0.20	0.24	0.27	0.39	0.24	0.28	0.22	0.32	4.16
1.5 - 2.5	0.66	0.49	0.32	0.45	0.56	0.52	0.26	0.20	0.30	0.28	0.70	0.98	0.90	0.50	0.33	0.43	7.86
2.5 - 3.5	0.29	0.27	0.44	0.56	1.13	0.45	0.22	0.15	0.38	0.52	1.17	2.10	2.13	0.55	0.21	0.28	10.85
3.5 - 4.5	0.11	0.09	0.30	0.71	1.63	0.48	0.23	0.20	0.33	0.62	1.09	2.39	3.45	0.67	0.07	0.05	12.41
4.5 - 5.5	0.02	0.05	0.18	1.19	1.63	0.38	0.16	0.13	0.18	0.41	0.87	2.13	4.65	0.83	0.07	0.02	12.93
5.5 - 6.5	0.00	0.01	0.24	1.04	1.68	0.09	0.11	0.09	0.20	0.35	0.46	1.49	5.52	0.54	0.02	0.00	11.84
6.5 - 7.5	0.00	0.04	0.18	0.89	1.34	0.16	0.05	0.11	0.18	0.27	0.46	0.95	5.21	0.41	0.02	0.01	10.29
7.5 - 8.5	0.01	0.01	0.18	0.99	1.09	0.07	0.06	0.13	0.20	0.40	0.24	0.68	4.60	0.52	0.01	0.01	9.22
8.5 - 9.5	0.00	0.00	0.17	0.55	0.50	0.00	0.04	0.05	0.12	0.45	0.30	0.46	3.07	0.45	0.00	0.00	6.17
9.5 - 10.5	0.00	0.00	0.12	0.78	0.17	0.02	0.02	0.02	0.18	0.46	0.26	0.30	2.15	0.24	0.00	0.00	4.74
10.5 - 11.5	0.00	0.00	0.13	0.52	0.11	0.00	0.02	0.01	0.02	0.43	0.20	0.39	1.17	0.30	0.00	0.00	3.32
11.5 - 12.5	0.00	0.00	0.12	0.17	0.00	0.00	0.00	0.00	0.02	0.39	0.20	0.21	0.72	0.13	0.00	0.00	1.96
12.5 - 13.5	0.00	0.00	0.09	0.10	0.00	0.00	0.01	0.00	0.02	0.28	0.22	0.21	0.32	0.05	0.00	0.00	1.29
13.5 - 14.5	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.13	0.16	0.11	0.10	0.06	0.00	0.00	0.60
14.5 - 15.5	0.00	0.00	0.06	0.05	0.00	0.00	0.00	0.00	0.05	0.12	0.23	0.07	0.01	0.02	0.00	0.00	0.62
15.5 - 16.5	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.10	0.05	0.02	0.00	0.00	0.00	0.34
16.5 - 17.5	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.04	0.11	0.09	0.02	0.02	0.00	0.00	0.00	0.34
17.5 - 18.5	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.11	0.04	0.01	0.01	0.00	0.00	0.20
18.5 - 19.5	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.01	0.01	0.00	0.00	0.00	0.17
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.06
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.04
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
> 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.04

All observational values are computed only for times with valid model data

Table 9: Distribution of simulated wind speed by direction

Wind Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	All
0 - 0.5	0.04	0.02	0.07	0.05	0.04	0.00	0.04	0.07	0.02	0.04	0.05	0.04	0.02	0.00	0.01	0.04	0.55
0.5 - 1.5	0.07	0.17	0.23	0.16	0.27	0.26	0.38	0.33	0.30	0.45	0.41	0.35	0.40	0.48	0.29	0.23	4.79
1.5 - 2.5	0.23	0.21	0.18	0.27	0.40	0.37	0.46	0.35	0.35	0.57	0.56	0.62	1.28	1.54	0.41	0.28	8.10
2.5 - 3.5	0.21	0.48	0.32	0.33	0.67	0.68	0.46	0.24	0.20	0.52	1.12	1.00	1.62	2.55	0.55	0.34	11.29
3.5 - 4.5	0.11	0.13	0.32	0.57	0.99	1.06	0.60	0.28	0.17	0.84	1.28	0.80	2.11	4.06	0.29	0.05	13.67
4.5 - 5.5	0.05	0.06	0.10	0.66	1.52	1.57	0.50	0.06	0.21	1.17	1.65	0.66	1.61	4.73	0.26	0.05	14.85
5.5 - 6.5	0.00	0.02	0.13	0.50	1.45	1.90	0.38	0.18	0.20	1.32	1.45	0.35	1.38	4.48	0.11	0.05	13.90
6.5 - 7.5	0.00	0.02	0.04	0.30	1.24	1.37	0.13	0.15	0.20	1.37	0.93	0.13	0.98	3.45	0.06	0.01	10.38
7.5 - 8.5	0.00	0.00	0.10	0.23	0.93	0.82	0.09	0.09	0.18	1.29	0.72	0.12	0.61	2.30	0.02	0.00	7.50
8.5 - 9.5	0.00	0.02	0.07	0.10	0.76	0.39	0.04	0.10	0.12	1.04	0.50	0.13	0.39	2.22	0.00	0.00	5.88
9.5 - 10.5	0.00	0.00	0.05	0.11	0.61	0.16	0.02	0.06	0.09	0.56	0.34	0.04	0.20	1.23	0.01	0.00	3.48
10.5 - 11.5	0.00	0.00	0.02	0.06	0.29	0.04	0.00	0.02	0.02	0.38	0.27	0.02	0.30	0.54	0.01	0.00	1.99
11.5 - 12.5	0.00	0.00	0.01	0.09	0.16	0.00	0.01	0.00	0.02	0.22	0.16	0.09	0.24	0.39	0.00	0.00	1.39
12.5 - 13.5	0.00	0.00	0.02	0.15	0.00	0.00	0.00	0.00	0.00	0.11	0.16	0.09	0.17	0.18	0.00	0.00	0.88
13.5 - 14.5	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.06	0.09	0.12	0.00	0.00	0.46
14.5 - 15.5	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.09	0.09	0.06	0.09	0.07	0.00	0.00	0.44
15.5 - 16.5	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.02	0.04	0.02	0.00	0.00	0.17
16.5 - 17.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.01	0.04	0.02	0.00	0.00	0.13
17.5 - 18.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00	0.07
18.5 - 19.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.04
19.5 - 20.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.5 - 21.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
21.5 - 22.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.5 - 23.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
23.5 - 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
$>$ 24.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.02

All model values are computed only for times with valid observations